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Effects of the AVAcore cooling device on measures of core temperature during 60 minutes of exercise in the heat

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Effects of the AVAcore cooling device on measures of core temperature during 60 minutes of exercise in the heat.

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B.Sc. College of Charleston 2000

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for the degree of

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Effects of the AVAcore cooling device on measures of core temperature during 60 minutes of exercise in the heat.

Chairperson: Dr. Brent Ruby

Exercising in hot, humid environments decreases the amount of work that the body can maintain. One of the main reasons for this decrease in performance is the increased core temperature during exercise. As the bodies’ core temperature increases due to metabolic and muscular work, the body must try and regulate the heat so that critical temperatures will not harm the body. One way that the body regulates the temperature of the core is through exchange of body heat into the environment. In hot, humid environments, when the temperature gradient is not as large from inside the body to outside, this becomes increasingly more difficult. The purpose of this research was to study the effects of a hand cooling device on measure of core temperature while exercising in the heat. A hand cooling device was chosen to take advantage of the vasculature used within the body to dissipate heat. Arteriovenous anastamoses (AVA) are located in the palmar aspect of the hands and are primarily used for dissipation of heat as the core temperature rises. Subjects were required to exercise at ~75% of their Ventilatory threshold (VT) for 60 minutes in a heat chamber set to a temperature of 32.2°C. Water temperature flowing through the hand cooling device was manipulated in 4 separate trials to see if cooler water had an increased ability to attenuate core temperature response. The trials were set as 19°C, 16°C, 13°C and a control trial where the device was worn without cool water circulating. No significant differences were found in measures of esophageal or rectal temperature between trials. Heart rate was also measured and showed only an increased HR over time in all trials, there was no interaction between trials. It was concluded that in this setting, the AVAcore device did not significantly affect core temperature response to exercise in the heat.
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Athletes have to overcome a number of physiological, mental and environmental factors to become successful in any given competition. All outside factors can affect athletes in different manners. The one factor that seems to treat every athlete that encounters it the same is high ambient temperature, better known as heat. Increased environmental heat impairs endurance performance and reduces the amount of work that can be done (4,7,8,19). This impairment of performance is not simply due to the high ambient temperature that may be encountered, but the adverse effects inside the athlete that it activates.

As an athlete begins any exercise or work, heat begins to accumulate within the body (5). As exercise intensity increases so does body temperature. The heat produced during exercise has the ability to raise body temp by 1°C every 5-7 minutes (18). The problem occurs with how the body dissipates the heat that is produced. As heat is produced via metabolism it is lost through exchange with the environment (5). During dynamic exercise this increased metabolic demand leads to elevated internal temperatures as well as an increase in skin blood flow and sweating (3). This is where the high ambient temperature takes effect. When the temperature surrounding the athlete is increased, a lower percentage of internally produced heat can be lost to the environment. As less of the internal heat is lost to the environment, body temperature begins to rise. There then seems to be a critical level of body temperature that can be reached before limiting endurance (6,8). Time to exhaustion is also linked to increased body
temperature (7,8). Metabolic activity can increase 10 fold during exercise thus bringing about that critical core temperature quickly while in a heated environment (5).

The challenge when exercising in the heat is how to help the body keep itself cool. During exercise the body naturally redirects blood flow to the peripheral tissues (Skin, Muscle) of the body for heat loss (5). Grahn and colleagues (5) have stated that primary heat loss occurs across the non-insulated or thinly insulated surfaces that are exposed to the environment. Greater heat exchange occurs over a larger gradient between internal and external environments (5). The skin is comprised of two types of vasculature which have different uses within the body. One structure is for nutritive properties of the skin while the other is specifically for the heat transfer with the environment (5). The skin has a series of venous plexuses and arteriovenous anastamoses (AVA) that are located only in the non-hairy regions of the skin such as the hands, feet, ears and face (5). Blood flow through these structures is directly related to body temperature with near zero flow in cold stress to as much as 60% of total cardiac output during heat stress (5).

There have been many different strategies utilized when dealing with heat stress factors. The common strategy is to precool the body or certain body parts by immersion in cold water prior to exercise (11,12,18,19,20). The main point of precooling the body prior to exercise is to try and create a greater heat sink. A greater heat sink means that the body temperature is lowered so that it may take longer to reach a critical temperature during exercise. Lowering of body temperature has been shown to improve performance in ambient temperatures of 18-25 °C (18). Marsh and colleagues (12) immersed the upper body of their subjects prior to exercise until there was a .3° C drop in rectal temperature.
temperature. This temperature drop was shown to increase power output over controls (12). Taafe and Marino showed increased cycling distance following whole body precooling in an ambient temperature of 31.4 °C (18). Wilson and colleagues (20) showed that lower body cooling doubled exercise time when compared to non cooled subjects (20). A number of other studies found stated similar results favorable for precooling the athletes’ body prior to exercise (9,11,19). While submersion of either the entire body, lower body or upper body seems to yield favorable results, it is not a useful tool for an athlete in competition. A more useful tool would be someway to attenuate the adverse effects of heat while not interfering with the competition.

Cheauvront and colleagues (4) looked at the effects of intermittent cooling on smaller portions of the body. This test involved a three piece suit that could be worn during exercise that would allow for more specified control of cooling. Compared to the constant cooling the intermittent cooling was shown to be 164-215% more effective (4). Hasengawa and colleagues (9) used a similar theory and had subjects wear a cooling jacket during exercise to exhaustion. The cooling jacket plus water consumption was shown to increase time to exhaustion over no cooling as well as hydration alone (9).

Grahn et al 2004, showed improved exercise endurance with use of the AVAcore RTX cooling device (6). In a previous study performed at the University of Montana Human Performance Lab, Lankford et al showed a reduced blood lactate level in the latter stages of cooling trials compared to control trials while using the same AVAcore RTX device (10).

The cooling provided during this study will be provided by the AVAcore RTX cooling device (AVAcore Technologies Inc.). This device circulates cool water to a
cooling plate upon which one hand is placed. This cooling plate is encased in a cuff that creates a negative pressure vacuum to enhance blood flow to the cooled hand. The idea of the device is that the cooled water will allow for greater heat transfer across the skin through conductive measures. The negative pressure cuff allows for greater blood flow into the AVA’s of the palm to maximize heat transfer. The original AVAcore RTX device has been modified for this study to allow for variable water temperatures to be circulated through the cooling plate. Water temperatures for this study will be 13 °C, 16 °C, 19 °C and a control trial with no water flow through the device.

Purpose

The purpose of this study was to examine the effects of a peripheral cooling advice on measures of core body temperature during exercise. Exercise was prescribed at 75-85% of the subjects Ventilatory Threshold (VT) for 60 minutes. Ambient temperature was set at 32.3 °C. Water temperature was varied between trials to record the effects of varying temperatures on the same measures of core body temperature.

Hypothesis One:

Rise in core body temperature will be attenuated in all cooling trials when compared to the control trial. The biggest difference will be seen in the coolest temperature.
Justification for Hypothesis One:
Cheuvront and colleagues (4) showed that constant cooling via a cooling vest significantly reduced changes in rectal temperature.

Hypothesis Two:
Skin temperature will be cooler on the hand that is inserted in the device. A lower skin temperature will also be recorded relative to the cooling trials.

Justification for Hypothesis Two:
A number of studies looking at precooling techniques showed lower skin temperatures when cooling was applied.

Hypothesis Three:
The water temperature flowing through the device will be varied when measured before entry into cooling plate and after exiting cooling plate. The biggest differential in temperature will be seen in the trial with the coolest water.

Justification for Hypothesis Three:
The physics of conductive heat transfer will apply here the body giving off heat to the cooler surface plate thus warming the water beneath. (5)

Hypothesis Five:
Heart Rate (HR) rise be attenuated between trials.

Justification for Hypothesis Five:
In a previous study Grahn and colleagues showed an attenuation of HR using this same RTX device (6). Also Cheuvront and colleagues showed attenuation in HR when using constant cooling techniques (4).
Rationale of Study:

Previous studies using this device have all used a temperature of 22 °C. In a study by Proulx et al (2002), cooler water temperature was shown to reduce body temperature in hyperthermic induced individuals (16). The goal was to see if cooler water temperature during exercise can attenuate body temperature responses.

Limitations:

Limitations to this study include: subject fitness, accuracy of temperature measuring devices, accuracy of heat chamber ambient temperature, ability of subject to refrain from swallowing (effect on ESO temp), accuracy of negative pressure cuff on RTX device, accuracy of VT estimated and subjects exercise and diet activity 24 hours prior to trials.

Delimitations:

All subjects in addition to being trained athletes were instructed to refrain from strenuous exercise 24 hours prior to trials. Subjects were also given an Ensure drink to consume 3 hours prior to trials and asked not to consume anything else but water in that time frame. Subjects performed all trials at the same time of day and subjects were given at least six days between trials. All trials were conducted from early to mid morning to try and help control ambient temperatures and humidity.
Physiology of Heat Stress

Heat is produced within the body by a variety of factors. Common sources of internal heat production are cellular and fuel metabolism (5). Additional heat may come from environmental sources including convection, conduction and radiation. Establishing temperature homeostasis is essential for all mammalian thermoregulatory systems to sustain life (5). Achieving homeostasis requires a delicate ability to match heat loss to heat gain. Behavioral mechanisms (clothing changes) and autonomic responses (sweating, redirected blood flow and salivating) both contribute to the noticeable responses to thermal challenges. Basic physics tells us that heat moves down a thermal gradient. Heat exchange through the environment is the only adaptation to increased internal temperature. Four factors affect environmental heat loss: Radiation, conduction, convection and evaporation.

The most accessible region of the body for heat exchange with the environment is the skin. This surface receives only minimal blood flow during rest (approximately 3.6% of total blood flow). During periods of exercise, when the heat production is increased due to muscular work, blood flow to the skin and surface areas are increased to improve heat dissipation into the environment. Passive heat transfer through adjustments in local circulation requires little resource expenditure. Evaporative heat loss mechanisms are more resource costly. Long periods of evaporative heat loss lead to lowered blood plasma levels. The body responds to lowered plasma levels by increasing internal temperature (5).
**Core temperature in heat**

Increased work causes a general increase in internal (core) temperature, heat production exceeds heat loss. When exercising in extreme hot or humid climates, heat dissipation is further decreased due to reduced evaporation and temperature gradients. Parkin and colleagues (14) had 8 male cyclists exercise to exhaustion at 70% VO\(^2\) max on three separate occasions. Trials were conducted at ambient temperatures of 3° C, 20° C and 40° C. They found muscle and rectal temperature to be higher at fatigue in the 40° C trial than in the two cooler trials. Exercise time was also significantly shorter in the 40° C trial.

Yanagimoto et al. (21), had 18 male subjects perform exercise at three different intensities after 60 minutes of acclimation to a 35° C and 50% relative humidity heat chamber. Exercise intensities were randomized at 30, 50 and 70% of VO\(^2\) max for 60 seconds with a 10 minute rest period between intensities. There were no significant esophageal temperature changes between intensities. Skin temperature was significantly higher in the 70% trial at the chest and forearm possibly showing an attempt to increase heat dissipation in these areas. Time to onset of sweating was shown to be significantly shorter with an increase in exercise intensity. This suggests that increased intensities create greater heat stores within the body.

Gregson et al.(7), had 6 men exercise at 70% max VO\(^2\) until exhaustion in 21.7° C temperature and 36.7% relative humidity on three occasions. One trial subjected the
participants to active heating before exercise. This consisted of running at 70% VO max until a rectal temperature of 38°C was obtained. A second trial had subjects passively heated prior to exercise by being submerged in a heated water tank (44°C) to the level of the gluteal fold until a rectal temperature of 38°C was achieved. Control trials had participants rest for a period of time and then begin the exercise protocol. Time to exhaustion was significantly lower in both of the heating groups. Measures of rectal and mean body temperature were increased during the initial 25 minutes of both heat trials when compared to control. As subjects reached exhaustion there was no significant difference in these measures. The researchers concluded that fatigue during exercise in moderate temperatures may be mediated by mechanisms that are associated with increased thermoregulatory strain.

Saunders et al. (17), had 6 male subjects acclimate for five twenty minutes and then exercise at 70% VO max for 5 minutes in either 20°C or 40°C. Muscular heat was shown to be significantly increased in the heated trial. Nielsen et al. (13), had 8 subjects exercise daily to exhaustion at 60% VO max for 9 days. As they became acclimated their time to exhaustion increased. Their rise in heart rate during exercise was also attenuated. It was concluded that high core temperature was a critical factor bringing about the onset of fatigue during exercise.
Effects of Cooling

Gonzalez-Alonso and colleagues (8) manipulated initial core temperature in 7 male cyclists and evaluated how initial temperature effected time to volitional exhaustion at 60% VO\textsuperscript{2} max. Subjects had core temperature manipulated by immersion in 17, 36 and 40° C water for 30 minutes. After cooling at 17° C mean esophageal temperature was 35.9° C, muscle temperature 34.4° C and skin temperature 29.5. The 36° C trial served as the control with mean esophageal temperature being 37.4° C, muscle temperature 37.3° C and skin temperature 34.2° C. The 40° C pre heating trial resulted in mean esophageal temperature of 38.2° C, muscle temperature of 38.4° C and skin temperature of 35.9° C. Despite the different starting core temperatures, all subjects reached volitional fatigue at relatively similar internal core temperatures of 40° C ± .1-.5° C. Even though there was no difference in temperature at fatigue between trials, time to exhaustion was inversely related to starting core temperature. Forearm blood flow was shown to be lower during the first 3-8 minutes of exercise in the cooled trial. This would suggest that the body is able to direct more blood flow to the working muscle following the cooled trial and this may be a reason for the increased time to exhaustion. The authors concluded that high internal body temperatures were the main reason for fatigue in these subjects regardless of initial core temperature.

Marsh and Gordan (12), had 13 trained male cyclists perform a 70 sec cycling power test after either 30 minutes of torso cooling (water immersion @ 18°C) or under control conditions. Power tests were done in the experimental or control trial after a 10 minute warm up period at 60% VO\textsuperscript{2} max. All exercise was performed in a heat chamber
set at an ambient temperature of 29° C and 80% relative humidity. This group found that mean power output increased after pre-cooling. They also found that core temperature, mean body temperature and skin temperatures were significantly decreased in the cooling trial. Heart rate was found to be lower in the control trial during the warm-up period. The authors concluded that pre-cooling enhanced short term high intensity exercise. It was also stated that the decreased HR during the warm up may indicate that blood flow to the periphery (for heat extraction) may be attenuated and thus central blood volume is not compromised.

Taaffe and Marino (18) studied the effects of whole body pre-cooling on 7 moderately trained male cyclists. Cyclists completed a thirty minute self paced cycle inside a heat chamber (31° C, 60% RH) on two separate occasions. In one trial subjects were submerged in a water bath (head and neck out) that was set at 8°-11° C. The second trial was considered a control trial and had subjects rest for 30 minutes prior to exercise. The researchers found that rectal temperature was lower between min 15 and 25. Distance cycled was increased during the cooling trial. Skin temperature was shown to be significantly lower throughout the cooling trial. The researchers concluded that pre cooling of the shell (skin) alone improves cycling performance.

Wilson et al. (20), studied the effects of lower body cooling (submerged to the supra-iliac crest) on thermoregulatory measures in 8 male cyclists. Cyclists were either pre-cooled in a 17.7° C water bath for thirty minutes (experimental) or immersed in a 35.1° C water bath (control) prior to exercise. Upon completion of the protocol subjects
cycled for 60 minutes at 60% of maximal $O_2$ uptake in a heat chamber set at an ambient temperature of 21.3° C. The experimental trial was shown to lower rectal, mean skin and mean body temperature. The experimental trial also doubled exercise time and delayed the onset of sweating. The researchers stated that pre-cooling decreased reliance on dry heat transfer and sweating during exercise resulting in lower rectal temperature throughout exercise. This also doubled the time needed to see a .5° C increase in internal temperature during exercise.

White and colleagues (19) compared lower body cooling with whole body cooling. Lower body cooling was defined as immersion up to the iliac crest in 20° C water and whole body cooling was immersion up to the clavicle. Immersion lasted for 30 minutes. The researchers studied the thermoregulatory responses of 11 healthy subjects who followed either treatment with 30 minutes of cycling at 60% VO$_2$ max in a heat chamber set at an ambient temperature of 30.3° C and 31.9% relative humidity. Rectal temperature was significantly lower during the initial 24 minutes of the exercise during the whole body pre-cooling trial. Skin temperature was also significantly lower in the whole body trial up to 14 minutes. Thermal sensation was lower (felt colder) during whole body cooling when compared with lower body only cooling. The authors concluded that both treatments prevented an excess rise in rectal temperature by lowering the initial core temperature. They also stated that lower body cooling may be more practical since it minimized negative perceptual effects.
Gonzalez-Alonso and colleagues (8) in a follow-up study of their previous research looked at the influence of the rate of increase in body temperature on heat exhaustion. The researchers used the same 7 subjects from the previous study cited earlier in this section. Subjects rested for 30 minutes in a supine position to achieve similar starting core temperatures for each trial. Subjects were to exercise in a heat chamber set at an ambient temperature of 41° C and 17% relative humidity until volitional exhaustion. Rates of heat storage were manipulated by wearing water perfused jackets that were circulated with either 42° C or 19° C water. All subjects reached exhaustion at similar muscle and rectal temperatures in all trials. Time to exhaustion was significantly lower in the 42° C water trial. The researchers stated that there was a large SE in the lower heat storage trial (19° C water) that was attributable to subjects working at different relative intensities. Two subjects exercised at intensities of approximately 71% VO² max and showed smaller decrements in between trials than two that worked at lower intensities. They concluded that the differences seen in the tolerance to heat strain appeared to be due to training status.

Hasegana et al (9) studied the effects of wearing a cooling jacket on thermal strain. They recruited 9 untrained male subjects and had them warm-up for 60 minutes at an intensity of 60% VO² max in a 32° C and 70-80% relative humidity heat chamber. Following the warm-up period subjects cycled to volitional exhaustion at 80% VO² max. There were four separate experimental procedures that the subjects followed during the 60 minute warm-up. Subjects either received no water or cooling, water intake every 5 minutes, cooling jacket alone or cooling jacket and water intake. The cooling jacket in
this study consisted of 8 flexible ice packs, four placed on the anterior portion of the vest and four placed on the posterior portion. In each trial the subjects rested in a 26° C room for 30 minutes prior to the start of exercise. In the trials with a cooling jacket, it was worn during this rest period. Water + cooling jacket trials and cooling trials alone showed a decreased rectal temperature over the 60 minute warm up period. HR in these two trails was also lower over the same period. Time to exhaustion was shown to be longer in the water + cooling trial. The researchers concluded that the combination of water intake and wearing of a cooling jacket decreased thermoregulatory strain and improved exercise performance.

Cheuvront et al. (4) studied the differences in intermittent regional cooling (IRC) versus continuous cooling (CC). 5 healthy male subjects were acclimatized a week before their first experimental trial in a hot-wet environment (35° C, 50% RH). Subjects had to complete six experimental trials while walking on a treadmill at an approximate power output of 225 W/m² for 80 minutes in a warm-dry climate (29.8° C, 30% RH). Experimental conditions were CC covering 72% of body surface area (BSA), IRC to two body regions covering 36% BSA with an on to off ratio of 2:2, IRC to two body regions covering 36% BSA with an on to off ratio of 4:4, IRC to two body regions covering 18% BSA with an on to off ratio of 1:3 or 2:6 and a no cooling trial (0% BSA). Water running through the jacket was set at 21° C. Changes in rectal temperature were significantly lower in all cooling trials when compared to no cooling. Cooling trials changed .5-.8° C while the no cooling trial had a change of 1.7° C. All cooling trials resulted in similar changes in heart rate response when compared to the no cooling trial.
The researchers concluded that intermittent regional cooling to smaller body surface areas was equally effective as constant cooling to a larger body surface area.

In unpublished data from the group at Stanford the effects on endurance exercise were studied while cooling the palm (6). 18 subjects (8 male and 10 female) performed testing in an environmental heat chamber that was set at an ambient temperature of 40° C and 25-45% relative humidity. All subjects wore a heat extraction device that provided a negative pressure gradient to draw blood into the palm. This device also had water circulating at a temperature of 22° C to cool the palm. Three experimental trials were performed, one with no cooling at all, one with cooling only and one with cooling as well as negative pressure. Subjects wore the cooling device and walked on a treadmill at 5.63 km/hr for 3 minutes with the slope increased 2% every three minutes. Once 90% of age estimated heart rate was achieved the exercise was terminated. Exercise duration generally lasted 25-45 minutes. Cooling and negative pressure significantly increased exercise duration by 43% and attenuated the rise in rectal temperature when compared to no cooling. It was concluded that continuous extraction of heat through the palm of one hand can increase aerobic endurance.
Chapter III
Methodology

Setting

All testing was performed in the Human Performance Lab at the University of Montana. Testing was conducted in a heat chamber with an ambient temperature of approximately 32.2° C.

Subjects

8 trained male subjects were recruited to participate in this study. Subjects were randomly assigned to complete three experimental trials and also served as their own control in a fourth trial. Subjects completed an IRB form approved by the University of Montana’s Human Subjects Committee prior to any testing.

Descriptive Data:

Prior to testing subjects were measured for weight using a calibrated digital scale (Belfor, Inc., Cedarburg, WI). Height and age were also recorded. Bike measurements were taken to establish seat height and post length on the Cardigus ergometer. Subjects were hydrostatically weighed with a digital underwater scale (Exertech, Dresbach, MN) to assess body composition. The average of three trials, within 100 grams, was taken to assess body density and the SIRI equation was used to estimate body fat percentage. Residual volume was estimated using established charts comparing height and age.
Exercise Testing

During the initial visit subjects performed a graded exercise test to establish VO$_2$ max and maximal watt output. The data collected was also used to estimate Ventilatory Threshold (VT). The graded exercise tests were performed in the heat chamber but at ambient room temperatures. The graded test consisted of a 10 minute warm-up @ 75 watts followed immediately by exercise until exhaustion using a 40 watt ramp protocol. The test was terminated when subjects could no longer sustain a cadence above 60 RPM. HR and gas data, VO$_2$ and VCO$_2$, were collected at the 5 minute mark of the 10 minute warm-up and continued to be collected throughout the remainder of the test. Gas data was recorded using the Parvo Medics (Salt Lake City, UT) calibrated metabolic cart. RPE was assessed on minute by minute bases using the 6-20 Borg scale throughout the test.

Heat Extraction device

Subjects placed the device on their left hand for all trials. The device consists of a negative pressure cuff and a cooling plate. The negative pressure cuff was monitored so that pressure inside the device was $\geq 15$ mmHG - $\leq 30$ mmHG. The internal plate was cooled with water circulating from an outside water bath. Subjects’ were asked to maintain constant contact with the palm of the hand and the cooling plate. The device allowed for slight movement of the hand and arm.
Trials:

All subjects were to complete four separate trials with at minimum of 6 days between trials. Subjects were scheduled during the same time of day to control for variations in circadian rhythm. Three hours prior to all trials subjects ingested an ensure meal replacement drink to normalize stomach content. Trials of 19° C, 16° C, 13° C and control were randomly ordered and assigned as subjects were recruited. Subjects were asked to refrain from any strenuous exercise on the day before a trial. They also were asked to follow the similar diets for each trial. All trials included a 10 minute warm-up at 75 watts followed by 60 minutes of exercise at 75%-85% of subjects VT. Upon completion of the 60 minute ride subjects had a two minute active rest period, pedaling against no resistance. A 5k time trial was then completed as fast as possible. Once the time trial was completed subjects received another two minute rest period, pedaling against no resistance. The trial concluded with a 20 min period pedaling against 75 watts. During all trials the cooling device was placed on the left hand after the 10 minute warm-up and was not removed until the completion of the trial. In the control trial the subject wore the device but water was not through the device.

Measurements

Temperature

Rectal temperature was measured using a Mon-a-Therm General Purpose thermistor set at a depth of 8 cm beyond the anal sphincter. Esophageal temperature was measured using the same brand thermistor set at a depth of ¼ of the subjects’ height. Room temperature was monitored throughout with a Mon-a-Therm thermistor placed...
inside the heat chamber. Water temperature through the device was measured using the Mon-a-Therm thermistors placed inside the tubes circulating water into and out of the AVAcore device. Skin temperature of the hands was assessed during the trial using Mon-a-therm skin temperature sensors placed between the 1st and 2nd metacarpal phalangeal joint on the right and left hand. All temperature measurements were recorded every second throughout the trial using the OM-3000 series Omega data logger.

**Gas**

Expired VO₂ and VCO₂ were collected at specified time points for 3 minutes using the Parvo Medics (Salt Lake City, UT) calibrated metabolic cart.

10 min warm-up:

Gas was recorded during minutes 5-8.

60 min ride:

Gas was recorded during min 5-10, 25-30 and 55-60.

20 minute recovery:

Gas was recorded during min 5-10 and 15-20.

**RPE**

60 min ride:

RPE was assessed using the 6-20 Borg scale at minutes 15, 30, 45 and 60.

Time Trial:

RPE and Thermal Comfort were assessed after completion of every kilometer during time trial.

20 min recovery:

RPE and Thermal Comfort were assessed at minutes 10 and 20.
**Heart Rate:**

Heart Rate was taken every 5 minutes throughout the trials with the exception coming during time trial. During the time trial, mean Heart Rate was reported. All heart rate data was recorded using Cardiosport heart rate monitors.

**Statistics**

**Temperature:**

Two way repeated measures ANOVAs were used to analyze temperature, RPE, thermal comfort, heart rate and gas data. All ANOVAs looked at Time x Trial comparisons.
CHAPTER IV
Results

Descriptive Data

Subjects

All subjects were measured for height (cm), weight (kg), body fat percentage and max VO2 prior to their first scheduled trial. Mean measures for this group were a height of 71.66 cm ± 2.21, weight of 74.08 kg ± 6.78, body fat % of 5.89 ± 2.81 and a VO2 max of 60.43 ml/kgmin. The mean age of the subjects was 24.88 ± 7.53. All individual results are listed in Table 1.

Room Temperature

The variable of room temperature showed no significant difference when looking at the time x trial interaction (F= 1.292, p= .1428). When looking at the main effect for trial there also was no significant difference (F=.303, p=.8227). The mean room temperatures for the control trials were 32.8 ± 2.88 °C. Mean temperature for the 19C trials were 32.6 ± 1.246 °C. Mean temperature for the 16C trials were 32.9 ± 2.215 °C. Mean temperature for the 13C trials were 32.1 ± .325 °C.

Water Temperature

In Flow Temperature

When looking at water temperature enter the device the time x trial interaction was significant (F=18.136, p=.0001). The mean data for each trial is reported in Table 2. Figure 1 shows all time points, across the 60 minutes, for each trial.
**Out Flow Temperature**

When looking at the water temperature leaving the device the time x trial interaction showed a significant difference (F=17.432, p=.0001). The mean data for each trial is reported in Table 3. Figure 2 shows all time points, across the 60 minutes, for each trial.

**In Flow vs Out Flow (each trial separate)**

**19C**

A significant difference is shown for the flow x time interaction (F=10.38, p=.0001). Figure 3 shows the in flow vs out flow, the out flow becomes significantly higher (p<0.05) for all time points beginning at minute 15.

**16C**

A significant difference is shown for the flow x time interaction (F=13.28, p=.0001). Figure 4 shows the in flow vs out flow, the out flow becomes significantly higher (p<0.05) for all time points beginning at minute 5.

**13C**

A significant difference is shown for the flow x time interaction (F=5.70, p=.0001). Figure 5 shows the in flow vs the out flow, the out flow becomes significantly higher (p<0.05) for all time points beginning minute 5.
**ΔIn Flow - Out Flow**

A time x trial interaction was shown when looking at the difference in water temperature in and out of the device (F=5.16, p=.0001). Figure 6 shows the mean differences for each trial across all time points. Table 4 shows the mean values for all trials.

**Rectal Temperature**

When looking at rectal temperature the time x trial interaction was not significant (F=1.24, p=.189). The main effect for trial was also not significant demonstrating similar responses between trials (F=.991, p=.419). There was a significant effect for time (F=47.28, p=.0001). Figure 7 shows all trials over all time points, rectal temperature is significantly increased (p<0.05) at all time points beginning at minute 10.

**Esophageal Temperature**

When looking at esophageal temperature the time x trial interaction was not significant (F=.933, p=.577). The main effect for trial was also not significant demonstrating a similar response across all trials (F=.305, p=.821). There was a significant effect for time (F= 10.82, p=.0001). Figure 8 shows all trials over all time points, esophageal temperature is significantly increased (p<0.05) at all time points beginning at minute 10.
Heart Rate

When looking at the variable of heart rate, time x trial interaction was not significant (F=.482, p=.993). The main effect for trial was also not significant demonstrating a similar response across all trials (F=.498, p=.688). There was a significant effect for time (F= 11.45, p=.0001). Figure 9 shows all trials over all time points, heart rate is significantly increased (p<0.05) at all time points beginning at minute 10.

Body Weight

No statistically significant differences were found between trials for change of body weight. Stats are shown in Table 5. The main effect showed a significant decrease in body weight over the course of each experimental trial.

RPE

No significant differences were found between trials for RPE at any time point of the 60 minute ride. The main effect for time was statistically significant showing a significant increase in RPE over time.
Skin Temperature

**Skin In**

When looking at the skin temperature of the hand inside the AVAcore device; there was a significant time x trial interaction ($F=2.94, p=.0001$). Figure 10 shows the mean values for all trials across all time points.

**Skin Out**

When looking at the skin temperature of the hand not inside the AVAcore device; there was no significant time x trial interaction ($F=1.19, p=.241$). There was also no significant effect of trial, suggesting that there were similar responses across all trials ($F=1.97, p=.241$). The mean value for the control trial was 34.2 ± 2.1°C. The mean value for the 19°C trial was 34.2 ± 1.7°C. The mean value for the 16°C trial was 34.5 ± 1.9°C. The mean value for the 13°C trial was 33.3 ± 2.1°C. There was a significant effect for time ($F=93.83, p=.0001$). Figure 11 shows all trials over all time points, skin out temperature is significantly increased ($p<0.05$) at all time points beginning at minute 10.
Tables and Graphs

Table 1

Descriptive Data (mean±SD).

<table>
<thead>
<tr>
<th>Subject (N=8)</th>
<th>Age (yr)</th>
<th>Height (in)</th>
<th>Weight (kg)</th>
<th>BF% (Siri)</th>
<th>FFM (kg)</th>
<th>FM (kg)</th>
<th>Peak VO2 (ml/kg*min)</th>
<th>Peak VO2 (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24.9±4.5</td>
<td>71.7±2.4</td>
<td>74.1±7.3</td>
<td>5.9±3.0</td>
<td>69.6±5.6</td>
<td>4.5±2.4</td>
<td>60.4±8.1</td>
<td>4.2±0.5</td>
</tr>
</tbody>
</table>

Table 2

In Flow Temperature

Mean Effect for Trial

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>29.7°C</td>
<td>2.7</td>
</tr>
<tr>
<td>19C</td>
<td>19.7°C</td>
<td>.45</td>
</tr>
<tr>
<td>16C</td>
<td>16.6°C</td>
<td>.25</td>
</tr>
<tr>
<td>13C</td>
<td>13.9°C</td>
<td>.26</td>
</tr>
</tbody>
</table>
Table 3

Out Flow Temperature
Mean Effect for Trial

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>29.4°C</td>
<td>2.4</td>
</tr>
<tr>
<td>19C</td>
<td>19.9°C</td>
<td>.42</td>
</tr>
<tr>
<td>16C</td>
<td>16.8°C</td>
<td>.21</td>
</tr>
<tr>
<td>13C</td>
<td>14.1°C</td>
<td>.19</td>
</tr>
</tbody>
</table>

Table 4

Δ In - Out Temperature
Mean Effect for Trial

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>.244°C</td>
<td>.523</td>
</tr>
<tr>
<td>19C</td>
<td>-.133°C*</td>
<td>.163</td>
</tr>
<tr>
<td>16C</td>
<td>-.262°C*</td>
<td>.139</td>
</tr>
<tr>
<td>13C</td>
<td>-.183°C*</td>
<td>.19</td>
</tr>
</tbody>
</table>

* - Significantly different from control trial (p<0.05)
Table 5

Body Weight

<table>
<thead>
<tr>
<th>Trial</th>
<th>PRE</th>
<th>POST</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>73.9</td>
<td>72.1*</td>
<td>1.7</td>
</tr>
<tr>
<td>19C</td>
<td>74.2</td>
<td>72.4*</td>
<td>1.8</td>
</tr>
<tr>
<td>16C</td>
<td>74.5</td>
<td>72.8*</td>
<td>1.7</td>
</tr>
<tr>
<td>13C</td>
<td>74.2</td>
<td>72.4*</td>
<td>1.8</td>
</tr>
</tbody>
</table>

* - showed main effect for time. Each trial was significantly different from itself when comparing post trial weight to pre trial weight. No significant differences were found between trials.

Table 5

Body Weight

<table>
<thead>
<tr>
<th>RPE</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>12.3</td>
<td>13.5</td>
<td>14.2</td>
<td>14.9</td>
</tr>
<tr>
<td>19</td>
<td>12.4</td>
<td>13.8</td>
<td>14.4</td>
<td>15.0</td>
</tr>
<tr>
<td>16</td>
<td>13.0</td>
<td>14.1</td>
<td>14.3</td>
<td>15.3</td>
</tr>
<tr>
<td>13</td>
<td>12.9</td>
<td>13.5</td>
<td>14.4</td>
<td>15.3</td>
</tr>
<tr>
<td>Overall mean</td>
<td>12.7±0.4</td>
<td>13.7±0.3*</td>
<td>14.3±0.1*</td>
<td>15.1±0.2*</td>
</tr>
</tbody>
</table>

* - showed main effect for time. No significant differences were found between trials.
Figure 1

Water temperature flowing into cooling device.

All trials were significantly different from one another at all time points (p<0.05).
Figure 2

Water temperature flowing out of cooling device

All trials were significantly different from one another at all time points (p<0.05).
Figure 3

Water temperature flowing into device as compared to water temperature flowing out of device (19C only).

This data contains the mean averages of all subjects during the 19C trial only.

Out flow temperature becomes significantly higher starting at minute 15.
Figure 4

Water temperature flowing into device as compared to water temperature flowing out of device (16C only).

This data contains the mean averages of all subjects during the 16C trial only.

Out flow temperature becomes significantly higher starting at minute 5.
Figure 5

Water temperature flowing into device as compared to water temperature flowing out of device (13C only).

This data is the mean average of entire subject pool over the 13C trial only.

Out flow temperature becomes significantly higher starting at minute 5.

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Figure 6

△ In Flow vs Out Flow All trials.
Rectal Temperature

All subjects data were pooled for individual trial differences

All time points are significantly different from 0-5 min averages starting at min 10 (p<0.05). There is no between trial significance.
Figure 8

Esophageal Temperature

All subjects data were pooled for individual trial differences.

All time points are significantly different from 0-5 min averages starting at min 10 (p<0.05). There is no between trial significance.
Figure 9

Heart Rate

All subjects data were pooled for individual trial differences. All time points are significantly different from 5 min averages starting at min 10 (p<0.05). There is no between trial significance.
Figure 10

Skin temperature of the hand on the inside of the cooling unit: Each trial mean contains all subject data for that specific trial.

The main effect for trial showed a significant difference between the control (33.91°C ± 2.73) and 13C trials (29.58°C ± 2.64). There was also a significant difference between the 19C (32.36°C ± 1.74) and 13C trials. The 16C trial was similar to all trials (32.36°C ± 1.74)
Figure 11

Skin temperature of the hand not in cooling device. All points are means over all subjects for each individual water temperature.

There was no significant difference for the main effect of trial
Chapter V
Discussion

The purpose of this study was to monitor the effect of cooler water temperatures running through a hand cooling device on measures of core temperature. Water temperature was manipulated with temperatures of 19°C, 16°C and 13°C. The fourth trial was a control trial where no cooling was used. In this study the main measures of core body temperature were esophageal and rectal temps.

Water Temperature

We manipulated water temperature flowing into the AVAcore cooling device in hopes that cooler water would attenuate the body's normal response to exercise in the heat. Significant differences were found in relation to the water temperature between all trials (Table 1, Figure1). When monitoring the change in water temperature into the device to that of the water leaving, we were able to show significant increases in the difference between the water into and water temperature out when compared to the control trial (Table 3). This shows that there was some heat transfer from the hand to the cooling plate and into the water. These results become more intriguing when we look at the mean differences of each trial individually. Upon reviewing the 19C, 16C and 13C trials respectively we notice that the change in temperature becomes significant at an earlier period between the 19C and the other trials (Figures 4-6). This may suggest that the cooler water enables the body a more efficient means of transporting heat away from the core. Proulx and colleagues looked at the effects of colder water baths and the ability to lower rectal temperature from 40°C to 37.5°C (16). They concluded that colder water temperature enabled a quicker reduction of rectal temperature. The reasoning, although trial purposes were different, may be similar in that a greater heat sink was developed.
across the body so heat was more easily transferred away from the core. Maximizing the bodies’ ability to give off internally produced heat may lead to increases in exercise production and lowered thermal responses.

**Skin Temperature**

Skin temperatures of the hand inside the cooling unit as well as skin temperature on the hand outside the cooling unit were also documented in the current study. When looking at the skin temperatures of the hand inside the cooling unit there was a significant difference between the 13C trials and the control and 19C trials. This suggests that the cooler water temperature flowing through the device was sufficient enough in the 13C trial to reduce skin temperature during exercise (Figure 10). The 16C trial was similar to all other trials. Previously stated studies involving precooling have shown a reduction in skin temperatures when cooling was applied. The advantages stated in most of these studies were that a greater heat sink was produced allowing for an increased work capacity. In the spectrum of this study the current findings would suggest that lower skin temperatures in the 13C trials may improve heat conduction onto the cooling plate during exercise, possibly by increasing the temperature gradient between the AVA’s and the water. Skin temperature on the hand not in the cooling unit showed no significant differences between trials, but did change significantly in all trials over time (Figure 11). This suggests that the warmer blood from the increased core temperature is being directed to the AVA’s which is in agreement with findings by Grahn and Heller (4).

**Heart Rate**
The heart rate data are consistent with previous studies conducted by this lab. Lankford et al (10) in an unpublished thesis showed only a significant HR difference at the initial 5 minute time point, but no significant difference thereafter between cooling trials in the heavier group (>18% body fat). A second lighter group (<10% body fat) showed no significant difference between trials at any time point. Each group did show a significant main effect for time. Grahn and Heller (6) showed a significant decrease in heart rate measurements when using a similar AVAcore cooling device. This difference in findings could be due to a one day acclimatization period that Grahn and Hellers’ subjects underwent. Our findings are also conflicting with the Cheuvront research that showed a decreased HR when subjects received constant cooling. In this study HR was shown to be significantly reduced under all cooling protocols (4). Subjects in the Cheuvront study were also stated to be heat acclimated. This transition period may have altered the bodies’ initial response to the stressor of heat and thus allowed for a more conducive heat transfer environment. The possible effects of acclimatizing to the heat will be further discussed later in the paper.

Core Temperature

One of the primary focuses of this study was to monitor the effects of the AVAcore cooling device on measures of body temperature during exercise. Cooler water running through the cooling device was hypothesized to reduce core temperature rise at the same exercise intensity. Previously stated results on water temperature findings would suggest the possibility for heat transfer. Results showed no significant difference between water temperature running through the cooling plate and attenuation of rectal temperature rise over time (Figure 8). All trials showed significant increases over time.
beginning at the 10 minute mark, but no significant differences at any time points between trials. Esophageal temperature measurements were also taken as another measure of core temperature and it was hypothesized that this temperature rise would also be attenuated by cooler temperatures. Results for esophageal temperature followed the same trends as rectal temperature. No significant differences were shown between trials, but differences over time were significant starting at the 10 minute mark (Figure 9).

Upon reviewing this data we can conclude that the exercise intensity was sufficient enough within all trials to produce an increase in core body temperature. The increases in measures of core temperature were not affected by the cooler water temperatures. The 13C, 16C, 19C and control trials showed no decrease in core temperature rise versus any of the other trials. We can conclude that cooler water temperatures showed no attenuation of rising core temperatures.

The absence of significant reductions in rectal temperature conflicts with the findings of the Cheuvront (4) research; which had shown a reduced rectal temperature at 22°C while receiving constant cooling. In the Cheuvront (4) study subjects were walking while receiving cooling over the legs, back, chest and head. Walking as compared to bike riding may have lead to the difference in rectal temperature changes. If intensity of biking is higher than that of walking, blood flow to the periphery may be reduced to allow greater flow to the working muscle. Also more body area was receiving cooling in the Cheuvront study when compared to the current study. This may have affected the attenuation of the core temperature response, due to a higher efficiency rate. Other studies that showed reduced rectal temperature involved precooling in a static state prior...
to exercise (12,18,19,20). Hasegawa and colleagues also showed reduced rectal temperature when subjects wore a cooling jacket and received water (9). Subjects in the Hasegawa study were exercising at 60% of VO2 max, subjects in the current study exercised at 50-55% of max; this may account for the discrepancy in rectal temperature attenuation. Also subjects in the Hasegawa study wore cooling jackets that may have provided cooling to a larger surface area which in turn may have aided heat stress reduction by allowing for a more efficient heat transfer. Grahn and colleagues also demonstrated an attenuated esophageal temperature response when using a similar device (6). Possibilities for the discrepancy in esophageal response could be due to mode of exercise (walking vs. biking) and also exercise intensity. Subjects in the Grahn study continued exercise until 90% of age estimated heart rate was achieved. Another difference in the two studies was that Grahn's’ subjects had a one day acclimation period; this may have affected the core temperature response.

The findings in this study show different results than what we had hypothesized. One possible reason may be any period of time subjects in other studies were acclimated to the heat. Acclimatization may have enabled the body to produce less of a heat stress response while exercising in the hot, humid environment. Yamazaki and Hamasaki (22) showed an increased skin vasodilatation in subjects that were acclimatized to heat over a six day period. Although the subjects in Grahn’s study were only introduced to the heat for one day, there may have been physiological adaptations which could be the reasoning behind the conflicting reports on rectal temperature.

Another possible reasoning for discrepancies could be the amount of vasodilation in the palmar aspects of the hand. The reasoning behind the AVAcore cooling device is
to use the AVA structures in the palm to induce a greater heat transfer across the skin; if the AVA’s become constricted (vasoconstriction) blood flow to the palmar aspect of the hand may become compromised. Time of day has been stated to alter the cutaneous response to whole body cooling, specifically suppressing vasodilation (1, 15.). All subjects in this study were tested during the early morning hours, possibly negating any positive effects of cooling. Cheuvront stated that skin cooling will cause vasoconstriction; which will decrease convective heat transfer from the core to the peripheral segments of the body (4). Skin temperatures between 32 °C and 35 °C have been shown to cause vasoconstriction. In the current studies the temperature of the skin in the device ranges from a mean of 29.58 °C to 33.91 °C. Pergola et al (15) have shown that maintaining a low skin temperature during exercise may in fact inhibit vasodilation. This could explain why Cheuvront had shown that intermittent cooling was more effective than constant cooling (4). Perhaps subjects in this study were affected by these same mechanisms thus reducing the effect that constant cooling may have during exercise.

Many precooling studies have been shown to increase exercise duration and intensity (6,9,18,20). A possible explanation of this phenomenon is that vasoconstriction increases blood flow to the working muscle (12). This increased flow to the working muscle may provide more fuel in the form of oxygenated blood, thus allowing more work before fatigue. If the present study did cause subjects to enter a vasoconstricted state when receiving cooling, then it would follow that exercise times or intensity may be increased. Another thesis study done concurrently within this study showed that 5 kilometer time trial performance (mean watt and time) showed no significant difference
over the cooling trials (2). If we accept the theory previously stated by Marsh, we may be able to rule out the thought that vasoconstriction due to lowered skin temperatures may have reduced the effect of cooling during these trials. However, since vasodilation or vasoconstriction was not monitored in this study, we cannot speculate as to their affects on these results.

**Conclusion**

Rise in core temperature has been noted as a limiting factor when exercising in the heat (4,6,11). The ability to control this rise may reduce the adverse effects of exercising under hot, humid conditions. Many studies that have been discussed previously used precooling techniques, not to attenuate the core temperature response, but to create a heat sink delaying the rise towards critical core temperature. The AVAcore cooling device claims to aid the body in dissipating heat more efficiently, thus allowing longer durations of exercise in the heat. Grahn and colleagues have shown that the device can attenuate HR response when compared to exercising without cooling effects (6). In other studies they have also shown that using the device will increase aerobic exercise time (6). While this present paper can say nothing of exercise time, there was no significant difference found to suggest that cooler water temperature reduces thermal effects on core temperature. There was evidence through skin temperature data and water temperature data that suggests heat is being extracted from the body. Lower water temperature through the device does seem to increase the difference in water temperature into and out of the cooling plate. Due to the small surface area that the device covers, it may not be able to dissipate heat at the rate it is being produced within the body over a long period of time. In conclusion the AVAcore cooling device did show
tendencies towards aiding the body in removal of heat during exercise but showed no significant differences in core temperature response.

Suggestions for Future Research

Future research should increase work time to see if the observed heat dissipation effects will eventually lower core temperature. Higher intensity work outputs should also be targeted so that a more critical core temperature can be reached. Higher core temperatures may increase the smaller effects seen in this study. Some research has shown increased work time and output when using the device. The methods behind these increases need to be researched to better understand the abilities of the device. More research should be done in the area of temperature regulation within the body using this device. Future studies should monitor skin vasodilation to ensure adequate blood flow for optimal heat dissipation across the skin.
References


13. Nielsen, B., Hales, J.R., Strange, S., Christensen, N.J., Warberg, J., Saltin, B., Human circulatory and thermoregulatory adaptations with heat acclimation and


